PIPING STRESS AND PIPE SUPPORT CRITERIA

Wood Contract No:	7650
Client Name:	INEOS
Project Title:	Project One
Project Location:	Antwerp, Belgium

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Section	Summary of Change	Revision number
6.1.1	Clarification at Section 6.1.1 – Add **Operating pumps to be at maximum operating temperature**	A3
7.28	Inclusion of new Section 7.28 Flare Design Considerations	A3
9.1.4	Referencing error Section 9.1.4 - 9.2 - Piping Criticality Diagram should read **9.3**	A3
11	Inclusion of new Section 11.	A3

1. PURPOSE

This specification outlines the requirements for the stress review of piping systems for INEOS Project One located in Antwerp, Belgium and, shall be followed when performing stress analysis during all stages of the Project.

2. SCOPE

This specification also provides piping stress design criteria and guidelines to ensure that the piping systems for the Project are in accordance with the code requirements of ASME B31.3, Process Piping. As necessary, the requirements of other codes shall be considered where applicable, e.g. ASME B31.1, B31.4 and B31.8.

3. TERMINOLOGY

The following terms are used throughout the document:

May	A permissive statement: an option neither mandatory nor specifically recommended.
Shall	Designates a requirement which is mandatory. Deviation will require approval via the formal process noted in 7650-8820-PR-000-0030, 'Technical Queries, Deviations and Waivers'.
Should	A specific recommendation where conformance is not mandatory.

4. REFERENCE DOCUMENTS

4.1 General

The latest edition, issue or revision of applicable codes and standards current at the effective date of the contract shall apply. All piping systems shall meet the requirements of this document, other referenced Project Specifications, relevant Codes, Standards and Statutory Regulations (where applicable).

4.2 Codes & Standards

The following international codes and standards shall apply as relevant:

Document Number	Title
American Society of Mechanical Engineers (ASME):	
ASME B31.1	Power Piping
ASME B31.3	Process Piping
ASME B31.4	Pipeline Transportation Systems for Liquids and Slurries
ASME B31.8	Gas Transmission and Distribution Piping Systems
ASME B73.1	Specification for Horizontal End Suction Centrifugal Pumps for Chemical Process
ASME B73.2	Specification for Vertical In-line Centrifugal Pumps for Chemical Process
ASME VIII Div. 1 and 2	Rules for the Construction of Pressure Vessels

American Petroleum Institute (API):	
API 520	Sizing, Selection and Installation of Pressure Relieving Devices in Refineries
API 610	Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries
API 617	Axial & Centrifugal Compressors and Expander compressors
API 618	Reciprocating Compressors for Petroleum, Chemical and Gas Industry Service
API 619	Rotary Type Positive Displacement Compressors for Petroleum, Petrochemical and Natural Gas Industries
API 620	Design and Construction of Large, Welded, Low-pressure Storage Tanks
API 650	Welded Tanks for Oil Storage
API 660	Shell & Tube Heat Exchangers
API 661	Air-Cooled Heat Exchangers for General Refinery Service
API 674	Positive Displacement Pumps - Reciprocating
API 675	Positive Displacement Pumps - Controlled Volume
Eurocode:	
Eurocode 0 NBN EN 1990	Basis for Structural design – (all Parts and Annexes)
Eurocode 1 NBN EN 1991	Actions on Structures – (all Parts and Annexes)
Eurocode 3 NBN EN 1993	Design of steel structures – (all Parts and Annexes)
Eurocode 8 NBN EN 1998	Design of Structures for earthquake resistance – (all Parts and Annexes)
International Organisation for Standardization (ISO)	
ISO 14692	Petroleum and natural gas industries — Glass-reinforced plastics (GRP) piping (All Parts and Annexes)
EN-ISO 5199 Appendix B	Technical Specifications for Centrifugal Pumps
National Electrical Manufacturers Association (NEMA)	
NEMA SM23	Steam Turbines for Mechanical Drive Service
National Fire Protection Association (NFPA)	
NFPA 20	Installation of Stationary Pumps for Fire Protection
Welding Research Council (WRC)	
WRC 107	Local Stresses in Spherical and Cylindrical Shells due to External Loadings
WRC 297	Local Stresses in Cylindrical Shells due to External Loadings on Nozzles – Supplement to WRC Bulletin 107
WRC 449	Guidelines for the Design and Installation of Pump Piping Systems

Expansion Joint Manufacturers Association (EJMA)	
EJMA – 10th Edition	Standards of the Expansion Joint Manufacturers Association
Emission Control	
PED 2014/68/EU	Pressure Equipment Directive
API 570	Piping Inspection Code: In-service Inspection, Rating, Repair, and Alteration of Piping Systems
API 574	Inspection Practices for Piping System Components
Vibrations and Dynamic loads induced failures	
Energy Institute	Guidelines for the Avoidance of Vibration Induced Fatigue Failure in Process Pipework (2nd Edition January 2008)
Energy Institute	ERRATA for Guidelines for the Avoidance of Vibration Induced Fatigue Failure in Process Pipework (2nd Edition January 2008)
API RP 688	Pulsation and Vibration Control in Positive Displacement Machinery Systems for Petroleum, Petrochemical, and Natural Gas Industry Services - First Edition

4.3 Project Standards

The following project standards shall apply as relevant:

Document Number	Title
7650-8820-SP-100-0001	Basic Engineering Design Data (BEDD)
7650-8430-PH-100-0001	Mechanical Philosophy
7650-8310-PH-100-0001	Civil and Structural Philosophy
7650-8230-SP-100-0001	Piping Standard
7650-8230-SP-100-0002	Piping Material Specification
7650-8230-SP-100-0016	Pipe Support Standard
7650-8440-SP-100-0010	Pressure Testing of Piping and Equipment
7650-8430-19-100-0004	Nozzle Design Loads
7650-8820-PR-100-0005	CE Marking Strategy

5. PIPE STRESS ANALYSIS PHILOSOPHY

The philosophy for the Pipe Stress Analysis undertaken for Project One shall be to produce an economic, flexible piping layout in accordance with the requirements of ASME B31 series and any other applicable code.

It shall be ensured that piping is routed and supported correctly so that no damage occurs to pipe and associated equipment due to the effects of thermal expansion, weight, pressure, slug flow, surge, shock, wind, earthquake, vibration, foundation settlement or any detrimental external loads.

All relevant and credible load combinations, displacements, stress range temperature differences imposed by design, operation, start-up, shutdown, transient, steam out and, design contingency conditions shall be considered.

5.1 Analysis Software

The Project approved program for the purpose of computer analysis is "CAESAR II" (latest version approved by the company for use).

5.2 Process Design Data

The process design data shall be included in the Project Line List which includes design, operating and upset temperatures, pressures and flowing medium density, slug flow, surge, 2-phase flow, vacuum service, acoustically induced vibration. Lines subject to more than 7000 cycles in the life of the plant, reference ASME B31.3 paragraph 300.2 - Definitions, shall also be included.

5.3 Piping Flexibility Stress Analysis Code Requirements

All onshore piping stress analysis shall comply with the requirements of ASME B31.1, and ASME B31.3 as applicable.

5.4 Design Conditions

Detailed site-specific design conditions are contained within the Basic engineering Design Data (BEDD) document number 7650-8820-SP-100-0001.

5.5 Design Life

For purposes of piping systems, the design life shall be a minimum of 20 years. Piping systems operating in the creep stress region shall be designed for 200000 hours.

5.6 Temperatures

Minimum Ambient design temperature is as per BEDD document. This shall be used as T3 for lines which do not have a lower design temperature in the project line list.

Minimum Installation temperature is: -18.3 °C. This shall be used for stress analysis, restraint and equipment loads for hot lines.

Maximum Installation temperature is: 36.7 °C. This shall be used for stress analysis, restraint and equipment loads for cold lines.

A maximum metal temperature (black body temperature) of 65 °C shall be used as a design temperature for Project One for uninsulated pipe. This shall be used in lieu of the design temperature when it is higher than the design temperature for uninsulated pipe, with no flow and subject to solar radiation.

5.7 Stress Range Calculations

When using the software Caesar II to check a ‘Piping System’, the “Liberal Stress Allowable” shall not be used. When it is necessary to use ‘’ “Liberal Stress Allowable”, this shall be justified and shall be subject to IPMT’s (Ineos Project Management Team), prior approval, which shall be distinctly documented in Stress Analysis Calculation Report.

For stress range calculation, whichever of the below listed equations produces the greatest temperature differential shall be used:

Maximum design temperature – Minimum installation temperature

Maximum installation temperature – Minimum design temperature

Maximum design temperature – Minimum design temperature

Piping design temperatures shall be obtained from the Project Line List.

5.8 Calculating Equipment/Pipe Support Loads

To calculate equipment nozzle loads, forces and moments on flanges, pipe support and anchor loads, the pipe temperature to be used for hot piping shall be at least the maximum design or black body (use highest) temperature. For cold piping use the minimum design temperature. The appropriate installation temperature listed in Section 5.6 above shall be used. Other temperature excursions due to start-up, shut down, steam out etc. shall also be considered.

Where the difference between design and operating temperatures is >30 Deg C within the project line list, process group shall be consulted to review/verify the design temperatures.

The use of maximum / minimum operating temperatures in lieu of the design temperatures to satisfy equipment nozzle loads / pipe support loads, for all load cases, shall require IPMT and NoBo's (Notified Body) prior approval.

CONTRACTOR shall identify equipment where allowable nozzle loads need to be minimised due to piping connections. This generally applies to items supplied by Licensors or Proprietary Equipment suppliers. For connections to such equipment, care shall be taken in advance in pipe routing and supporting to avoid problems at a later stage.

Rigid pipe supports shall be utilized to maximum extent to minimise use of spring supports and hanger rods where design permits.

Cold Spring/Pull is not permitted to be used to reduce loads on equipment and supports.

5.9 Wind

Exerted wind loads shall be considered on piping systems with an outside diameter of 10” and larger including insulation and, at elevation 10 meters and higher.

When considering wind, the velocity profile shall be developed based on the following:

- Maximum Velocity is as per BEDD
- Prevailing Direction – From the South West.

Structural and mechanical wind load pressures are derived from the methodology defined within Eurocode 1, NBN EN 1991-1-4 and the supplementary National Annex NBN EN 1991-1-4-ANB.

The wind shall be considered to act in any (horizontal) direction and the most unfavourable condition shall be considered. Calculations shall be done for wind in two orthogonal directions considering the +ve and -ve effects of each of the two directions (for example +X, -X, +Z & -Z).

A wind shape factor (Cf) of 0.9 shall be included in wind case analysis of piping. The effects of shielding by the structure and piping may also be taken into account, if deemed necessary.

The natural frequencies of piping elements and structures shall be checked to ensure that they do not coincide with the vortex shedding frequency. Insulation applied to piping increases its overall projected pipe area and shall be included in the wind load calculations.

Winds of 8 to 18 m/s can cause vortex shedding and excitation in the 30 Hz and higher range that can cause fatigue failure in smaller line sizes particularly susceptible to fatigue type failures. To analyse vortex shedding, harmonic analysis methods shall be used.

5.10 Earthquake

All line sizes for hazardous fluids and liquid lines 4"NB and above (subject to discussion with NoBo), and all small bore branch connections with large point loads (heavy flanged valves,ie instrument connections) shall be analysed for seismic criteria.

Seismic analysis in CAESAR II shall be carried out using either dynamic or static methods. The "Equivalent elastic static method" shall be used using the 'g' load multiplication factor. The static loading magnitude is considered to be in direct proportion to the piping element's weight – for example if an earthquake is modelled with a 0.33g force (load) in the X direction, then a force equal to one third of the system's weight is applied to the pipe uniformly in the X direction.

Earthquake loads and static 'g' load multiplication factor shall be calculated per Eurocode 8, Civil and Structural Philosophy and as per BEDD data.

The resulting horizontal and vertical 'g' load static accelerations can then be used in piping stress calculations (the vertical component will be taken care of in normal supporting techniques and is not included in stress analysis).

Wind and earthquake forces shall not be considered as acting concurrently.

6. EQUIPMENT DESIGN CONSIDERATIONS FOR STRESS ANALYSIS

6.1 Pumps

6.1.1 <u>Centrifugal Pumps</u>

Pipework at locations with multiple pumps shall be analysed for all possible operating conditions, including one pump operating and another at stand-by. If this occurs, three different cases shall be considered: -

1. Both pumps operating.
2. Pump A operating, Pump B stand-by.
3. Pump B operating, Pump A stand-by.

Pumps can also be arranged with two pumps operating and another at stand-by. If this occurs, four different cases shall be considered: -

1. Pumps A, B and C operating.
2. Pumps A & B operating, Pump C stand-by.
3. Pumps A & C operating, Pump B stand-by.
4. Pumps B & C operating, Pump A stand-by.

Operating pumps to be at maximum operating temperature.

The pipe to / from the stand-by pump can be taken as the average of the maximum operating temperature and the installation temperature (or as determined by heat transfer calculations) if the check valve is fitted with a by-pass to facilitate a 'warm up'.

If a by-pass is not provided, the temperature of the dead leg for the stand-by pump from the tee to the block valve, for both suction and discharge lines, shall be considered to be as the average of the maximum operating temperature and the installation temperature. The temperature of the piping from the block valve to the pump shall be taken as ambient.

Where springs are positioned local to pump nozzles, a separate nozzle loading check is required to cover the short-term condition where the springs are active, but the line is empty.

Differential settlement shall be considered. Where possible to minimise differential settlement the first support local to the pump shall be located on the pump foundation. The first rigid support local to the pump shall be adjustable.

The allowable loads at centrifugal pump nozzles shall be in accordance with those specified in API 610 Table 5 as a minimum, or those specified by the pump manufacturer and accepted by IPMT.

For ISO 5199 pumps, assessment of applied nozzle loads shall be to EN-ISO 5199 Appendix B as a minimum, or those specified by the manufacturer and accepted by IPMT.

6.1.2 Vertical In-Line Pumps

Small vertical in-line pumps (15 kW or less) shall be supported immediately adjacent to suction and discharge flanges using conventional pipe supports. Piping forces shall be determined with the pump considered as a rigid, but as an unanchored segment of the piping system.

Larger vertical pumps furnished with casing foot-mounts shall be supported on suitable foundations.

Loads shall be in accordance with API 610 Table 5 criteria as minimum, or those specified by the manufacturer and accepted by IPMT.

6.2 Centrifugal Compressors and Steam Turbines

6.2.1 Design Conditions

In order to develop the most severe loadings on the equipment, all possible operating and upset scenarios shall be considered.

6.2.2 Temperature

Maximum operating temperatures for each operating condition under consideration can be used in analysis subject to IPMT's prior approval. The support and anchor displacements resulting from the expansion or contraction of the compressors/turbines and attached equipment due to temperature changes shall be included in the analysis. Displacements of the equipment nozzles shall be included.

6.2.3 Pressure

For the purposes of calculating nozzle loads, maximum operating pressures for each operating condition under consideration shall be used in analysis. For large diameter piping pressure effects (e.g. pressure stiffening, Bourdon effects, etc.) can be considerable and shall be considered in the analysis.

6.2.4 Wind

The Project specific static wind pressure profile shall be used in the analysis. Wind direction shall be considered in determining the most severe equipment loadings.

Where wind loads are excessive, it may be necessary to consider the natural shielding of the piping from the surroundings (piping, steelwork, equipment, etc.) in order to reduce loads on the compressors/turbines.

6.2.5 Allowable Loads

The nozzle forces and moments which may be applied to Centrifugal Compressor flanges during piping design shall be limited to those values allowed using the equation of API 617, 8th Edition, Part 2, Annex F, or those values acceptable to both IPMT and the manufacturer.

The allowable nozzle forces and moments which may be applied to Steam Turbine flanges during piping design shall be limited to NEMA SM-23, or the manufacturer's limitation's, whichever are larger, or those values acceptable to both IPMT and the manufacturer.

Calculated forces and moments for each compressor or turbine exceeding allowable shall be sent to the equipment engineer for their records and the manufacturer's approval. A statement regarding the allowable nozzle loads shall be included in the mechanical requisition for each piece of equipment. The Lead Stress Engineer shall inform the Lead Equipment Engineer of the nozzle load requirements and agree early in the FEED/EPC phase of the project.

6.2.6 Friction Effect

A friction and non-friction analysis shall be considered for all compressors and steam turbines.

6.2.7 Pipe Support and Restraints

Pedestal type springs supports shall be avoided where possible and shall not be used if horizontal movement exceeds 5mm due to frictional loads and the possibility of the spring binding.

The restraints local to the compressor/turbine, protecting the nozzle, shall be designed to facilitate site adjustment.

6.3 Reciprocating/Positive Displacement Pumps & Compressors

Reciprocating/positive displacement pumps and compressors generate both mechanical & pulsation excitation where the resultant out of balance dynamic forces directly load the pipework and support structure.

Mechanical excitation is induced via dynamic forces which directly load any pipework connected to the machine or cause vibration in the supporting structure, which then excite the pipework supported from the structure.

Pulsation excitation in the suction and discharge pipes is induced via oscillating pressure fluctuations in the process fluid, by virtue, of the machine's operation. Pulsation dampers are often specified to mitigate pressure pulsations & vibrations and they should have at least 10 times the area of the pipe. The vibration will exist from the machine to a receiver, or to a point that can be considered to be at an infinite length (approx. 60 metres), in order for the pulsation to decay. Air coolers and shell and tube heat exchangers cannot be considered as receivers.

In order to prevent the vibrations from mechanical excitation and pressure pulsations becoming a problem, piping systems shall be supported, ensuring that, as a 'rule-of -thumb' a +/- 20% separation is made between source/excitation frequencies (including harmonics) and the acoustic/piping natural frequencies. The source/excitation frequencies shall be agreed with the compressor vendor but will not normally be higher than the 4th natural frequency of the compressor.

Pipe supports shall be of the hold-down type and located to ensure the natural frequency of the piping spans have the +/- 20% separation from the vendor advised source/excitation frequencies. A static frequency (modal) analysis should be run in Caesar II to check this. Spacing between the supports shall be varied so as to prevent adjacent spans having identical frequencies.

Pipe support frequency shall use the +/- 20% separation from the source/excitation frequencies, or ideally be much higher. To achieve this, piping shall be routed at low level, ideally on concrete sleepers until the point where excitation/pulsation decays to negligible amounts.

Consideration shall be given to including an acoustic isolating pad between pipe support and pipe, or pipe support and steel, to prevent excitation of supporting structure / other lines. Vent and drain connections shall be braced with two planes and the bracing at 90° separation.

The above work shall be completed before the Compressor vendor carries out an acoustic simulation and mechanical response study, in accordance with API 618 (reciprocating compressors), API 674 (positive displacement-reciprocating pumps) or API 675 (positive displacement-controlled volume pumps).

The force generated by the pressure pulse (F) is calculated by:

F = ((Design Pressure) x (Inside Area of Pipe) x (maximum % Pressure Surge))

This force can be used as a basis for structural design at changes of direction and hold-down supports.

6.4 Air Coolers

The header boxes for multiple bundled Air Coolers shall be supported on PTFE slide plates. In general, the inlet piping to multiple bundled Air Coolers shall be as rigid as possible local to the header boxes; therefore, the piping will move the header boxes.

The header box movement of a multiple bundled Air Cooler can be controlled in two ways: -

1. One of the centre header boxes is fixed to the support frame.
2. The inlet header pipe is anchored.

In either case, a suitable clearance shall be provided between the header boxes and the supporting framework. It should be noted that the minimum clearance required by API 661 is often insufficient and piping shall always check. This should be checked at the first issue of vendor drawings.

The resulting loads, due to the rigid piping, will be mainly shear forces and not bending moments, these loads will normally be acceptable.

At “even-pass” units the outlet piping shall have sufficient flexibility to cater for the lateral movement of the air cooler boxes.

At “odd-pass” units the outlet piping shall allow for failure of a single fan. Temperature of the outlet piping shall be assumed to be the same as the inlet piping. If this causes problems a more accurate outlet temperature is to be obtained from the Process/Mechanical Department.

If isolation valves are located at each Air Cooler bundle, a case of one bundle at stand-by and the others operating shall be considered. Process shall advise on the different operating possibilities.

The calculated loads on Air-Cooled Heat Exchanger nozzles shall be within the allowable as per API 661, Figure 6, Table 4, or manufacturers limitations whichever are larger. The statement regarding the allowable nozzle loads shall be included in the mechanical requisition.

6.5 Storage Tanks

Differential settlement is a potential issue for storage tanks. Settlement data shall be obtained prior to the design of piping and this shall provide the:

Maximum amount of settlement (and recovery) that will occur following construction and hydro test.

Maximum amount of settlement (after hydrotest) that will occur during operation and period of time over which it will occur.

When large storage tanks are filled the walls bulge and nozzles located in the lower course of the tank rotate downwards. Any restraint on this rotation by the stiffness of the connected piping will cause a stress in the tank shell that shall be limited to values defined by API 650. For API 650 tanks, use the method provided in Appendix P.

Seismic excitation is a potential issue for storage tanks and the connected piping at the nozzle shell interface due to the potential different seismic behaviours of the tank and piping. API 650 section E.7.3 / Table E.8 details seismic movements between tanks and adjacent supports. Vertical and horizontal seismic effects on tanks based on data from BEDD / Civil and Structural Philosophy is also a potential issue. These effects shall be considered in the Caesar II analysis of piping as required.

Piping to and from tanks shall be routed to run parallel to the tank wall as close to the tank wall as practical. This reduces the amount of vertical displacement of the pipe due to tank bulge, and also reduces the longitudinal moment acting on the tank. This will, however, increase the torsional moment, but this is of minor consequence as according to API 650, there is no maximum allowable torsional moment.

The combined effects of settlement and tank bulge may require supporting the piping on spring type supports. The use of springs shall be limited due to the possibility of the line becoming drained and an excessive upward load being applied to the tank nozzle.

To enable design to proceed, it is imperative that the values of tank bulge (including thermal radial growth), nozzle rotation, tank nozzle stiffness and the method of calculation are agreed with the equipment engineer early in the project. Tanks to other codes require appropriate review and consultation with the equipment engineer / vendor.

For hydrotesting, section 7.3.7.1 of API 650 shall be applied for adjoining piping.

6.6 Packaged Equipment

The piping to packaged equipment shall be routed in such a way as to minimise the interfaces and to keep the loadings to a minimum. Minimum nozzle loading requirements for Package Equipment can be found in 7650-8430-19-100-0004. Similarly, the CONTRACTOR shall instruct the package equipment supplier to anchor the interface piping within their battery limits as far as practical to minimise the design interfaces with piping provided by CONTRACTOR.

6.7 Pressure Vessels & Shell and Tube Heat Exchangers

Piping connected to pressure vessels and shell and tube heat exchangers shall be analysed for all possible cases including start-up, steam-out and maximum operating/design conditions.

Nozzles should be modelled as rigid and calculated nozzle loads assessed against equipment manufacturer allowable loads, or the applicable industrial code allowables such as API 660 for Shell & Tube Heat Exchangers, whichever is higher.

The fixed end of horizontal shell and tube heat exchangers and drums shall be determined by the Piping Stress Engineer.

7. GENERAL STRESS CONSIDERATIONS

7.1 Friction

The effects of friction on supports and strain sensitive equipment shall be considered. See friction table below.

The coefficient of friction (μ) acting at pipe supports shall be as follows:

Steel to steel	0.40
Steel to steel round bar	0.30
Steel to concrete	0.60
Teflon to steel	0.20
Teflon to Teflon	0.10
Roller support (dry bearing type)	0.10 – 0.15
Sand to tape wrap	0.40
Sand to FBE coated	0.40
Sand to plastic coating	0.40
Sand to concrete	0.40

PTFE may be used to reduce equipment loads to within acceptable limits where no logical piping routing change can be achieved. It shall not be used to reduce friction loads for track / rack lines, unless for specific design reasons.

7.2 Flange Leakage

Flanges with class 600 rating or higher shall be qualified for flange leakage using NC-3658.3 method noting its limitations. Flanged joints for lower rated systems should be reviewed using 'Kellogg' Equivalent Pressure method based on ASME B16.5 Pressure Temperature table.

ASME Section VIII Division I Appendix 2 method shall be used when neither NC3658.3 nor the Equivalent Pressure Method provide satisfactory results.

Finite Element methods can be used when ASME Section VIII Division I Appendix 2 doesn't result in allowable loads.

7.3 Pipe Spans/Sag

Piping spans are limited to a maximum mid span deflection due to self-weight of the piping, plus insulation and cladding and contents to 12 mm.

For all piping analysis, mid-point nodes shall be considered in order to monitor deflections and stresses.

7.4 Relief Valve Discharge Loads

Relief valve discharge forces shall be calculated in accordance with API RP 520 Part II. Suitable restraints will be required to absorb these forces and prevent overloading and over stressing of the piping or valve in line with good engineering practices. A dynamic factor of 2 shall be applied.

Piping to and from relief valves shall be self-supporting with relief valves removed.

7.5 Control Valve Out of Balance loads

At control valve stations where out of balance forces / flow surges and vibration can occur, suitable restraints (linestops /guides/hold-down) will be required to absorb these forces and prevent overloading and over stressing of the piping or valve.

7.6 2-Phase Flow and Slug Flow

Where 2-phase flow or slug flow is predicted in a piping system, loads shall be calculated and considered at all changes of direction. Particular attention shall be given to the pipe support design for these systems. Pipe supports shall be capable of restraining the piping system without concurrently overstressing the pipe in the thermal expansion cases. Dynamic loads and analysis shall be in accordance with Energy Institute “Guidelines for the Avoidance of Vibration Induced Fatigue Failure in Process Pipework”, see section 11 for more details.

7.7 Surge Analysis

Surge in liquid filled systems not only determines the design pressure, but also creates unbalanced forces.

Loads due to surge pressure caused by the rapid opening or closing of valves, pump start-up, pump trip due to loss of power in long circuits containing liquids, shall be taken into consideration at changes of direction. Surge effects shall be considered on any line with fast acting Emergency Shutdown (ESD) type valves / firewater lines and anywhere specified by the Process Group.

The Magnitude of the out of balance dynamic force shall be calculated based on a hydraulic surge analysis report. Linestops / Guides / local pipe support reinforcement / support stiffness’s shall be designed to control all out of balance forces, see section 11 for more details.

7.8 Hydrotest

All lines shall be pressure tested as indicated in the Project Line List.

A hydrotest load case with the piping full of water is required for all lines, including lines for gas and vapour, unless another test medium is agreed with IPMT.

7.9 Steam Out

Lines that are subject to steam out shall be considered for flexibility analysis at the steam out temperature, if it is in excess of the design temperature. The analysis shall consider whether the equipment and the piping are steamed out together or separately.

7.10 Vessel Skirt Temperature

Vessel skirt temperature and movements shall be modelled in stress analysis and recorded on the stress isometric.

7.11 Vacuum Stability

For large and comparatively thin walled pipe, the long straight runs can be subject to vacuum instability. The solution is to provide stiffening rings. The actual run length influences this and any change such as an expansion loop breaks up the run and may render the stiffening rings unnecessary. Changing wall thickness should also be considered. It is unusual for piping of NPS 12” or smaller to be subject to vacuum instability since a large external pressure would be required.

The phenomenon frequently occurs on lines subject to steam out and lines subject to hydraulic hammer (fast closing valves). Where partial vacuum occurs, the line shall be designed and validated for full vacuum.

Vacuum stability calculations for piping shall be in accordance with ASME VIII div 1 section UG-28.

Vacuum requirements shall be indicated on the Project Line List.

7.12 Bourdon Pressure

Causes straight pipe to elongate and bends to open up, these effects shall be considered in the Caesar II analysis of piping as required.

7.13 Acoustically Induced Vibration

Any lines subject to acoustic fatigue shall be identified on the Project Line List. The measures to be used to safeguard against acoustic fatigue shall be identified by CONTRACTOR. Contractor shall use a ‘Specialist Consultant in Acoustic Induced Vibration’. See section 11 for more details.

7.14 Flow Velocity Induced Vibration

Any lines subject to flow induced vibration shall be identified on the Project Line List. The measures to be used to safeguard against flow induced fatigue shall be identified by CONTRACTOR. Contractor shall use a 'Specialist Consultant in Flow analysis' for this purpose. See section 11 for more details.

7.15 45° Lateral Connections

The effect of 45-degree connections shall be reflected in any stress analysis with respect to their effect on stress raisers. Stress Intensification Factor (SIF) Indices should be considered carefully in each case and stated in all calculations and included on the stress isometric.

For flexibility purposes, testing has shown that these branches act like unreinforced connections. Typically, a factor is applied to the stress intensification factor for the unreinforced fabricated 90° tee. In the absence of more applicable information for a 45° branch, a conservative multiplying factor applied to the 90° unreinforced fabricated tee SIF’s (In-Plane and Out of Plane) of 2.25 shall be used.

Finite Element Analysis (FEA) is recommended as a validation for this type of connection where aforementioned multiplication factor generates stress / routing issues.

7.16 Insulation Density

Equivalent densities shall be calculated taking into account the cladding weight.

7.17 Sway (Flexibility of supports and structures)

The effect of displacement (sway) of equipment and structures due to seismic or wind shall be included in analysing flexibility of critical piping systems. Displacement strains shall be analysed in accordance with ASME B31.3 section 319.2 requirements. Associated loadings and displacement stress cases are given in the design load cases described in section 8.3.

7.18 Equipment Settlement

The provisional differential settlement values in Attachment 1 will apply unless or until Civil / Structural Engineering Group provide applicable differential settlement values.

7.19 Standard Pipe Supports

Standard pipe supports shall be chosen to withstand loads determined in stress analysis / pipe support review.

7.20 Supporting

All lines to be supported in accordance with the limitations set by the applicable codes listed herein. Maximum deflection between supports to be limited to 12mm. As infinitely stiff supporting members are impractical to construct, the stiffness of these members shall be taken into account at those support locations deemed as critical by the Stress Engineer. All piping shall be supported on pipe shoes, piping shall never be installed direct on the beam or rubbing bars, U-bolt clamps are not allowed. Large diameter thin wall lines shall be analysed for crushing loads at the support point and reinforced as necessary. Insulated piping that is not protected by a building or shelter shall not be supported by hanger type supports, no support element to penetrate the insulation from the top (so as to protect against ingress of water).

7.21 Special Pipe Supports

Special Pipe Support Drawings are used to identify non-standard pipe support requirements.

All Special Pipe Support Drawings shall be allocated a unique reference number, indexed, detailed and issued formally for design and construction.

Special Pipe Supports are to be kept to a minimum.

7.22 Spring Supports

The use of spring supports shall be minimised by careful consideration of support location and alternative pipe routing.

7.23 Temporary Pipe Supports

The use of temporary pipe supports for hydrotest and for transportation shall be avoided.

7.24 Indentation

Large diameter, thin wall pipes can deform locally when sitting on narrow supports e.g. un-insulated lines sitting on steelwork or due to loadings from linestops and guides. These local stresses shall be investigated and local reinforcement at the support point specified as required, or for weight effects shorter spans may be specified.

7.25 Welded Attachments – Trunnions, Stops, Lugs & Pipe Shoes

Local stresses in parent pipe / welds / attachments / supports welded to piping shall be reviewed to check whether reinforcing pads are required.

7.26 Thermal Movements

The following recommended practice for determining maximum horizontal displacement values:

1) In process units, the maximum movement at each side of a loop should not be more than 150 mm.
2) In offsite areas, the maximum movement at each side of a loop should not be more than 300 mm.
3) The guideline for the thermal movement at the corner when pipe changes directions should be limited to a maximum of 150mm in the process area and 250mm in the offsite area.
4) Thermal movements at branch connections should be limited to 75 mm to avoid overstressed branch connections.

7.27 Reinforced Thermoset Resin (RTR) Pipe and other, Non-Metallic Pipe

The Vendor shall carry out stress analysis of non-metallic piping such as RTR and HDPE (High Density Polyethylene) piping etc. The Vendor shall design and manufacture the piping to ISO14692. Surge and stress analysis of RTR and HDPE piping, buried or above ground, should be performed by specialists as RTR and HDPE behaves differently in tension to elastic homogeneous materials such as steel.

7.28 Flare design considerations

Flare system piping shall be designed, anchored and guided to resist the forward, lateral and upward dynamic forces developed at changes in direction due to high velocity vapours and condensate liquid if dictated by process (see section 11 for more details) as well as to accommodate sudden thermal expansion or contraction.

If flare system design is performed considering only vapor flow and no consideration or design is made for liquid slug flow, the flare system headers and supports shall be designed with the allowance for liquid presence as follows:

Up to

DN 250 (10"): FULL

DN300 – DN 400 (12" - 16"): Half Full

DN450 – DN 900 (18" - 36"): Third Full

DN 950 (38") Up: Quarter Full

8. FLEXIBILITY ANALYSIS (STRESS ANALYSIS – SPECIFIC FUNCTIONS)

8.1 General

To avoid one large set of all load cases, different load case sets for stress analysis may be used. (i.e. a set for the basic design loads and a different set for occasional loads). Typical load case combinations have been created in section 8.3 below.

Irrespective of the number of load cases, CAESAR II Input files shall contain all the input data in one file regardless of whether the parameters are used in that particular load case or not. Whether the parameter is used or not will be controlled by the load case attributed to the file. Following this protocol will mean that there is only one input file to update with any modifications, subsequently the associated load cases can simply be imported as required.

8.2 CAESAR II Modelling of Equipment

8.2.1 Static Equipment

Vessel and Exchanger Nozzles shall be modelled as rigid; however, flexibility of nozzles in vessels and exchangers may be included in the analysis if required. Thermal Displacements of nozzles due to vessel thermal growth shall be evaluated and input into analysis.

Start-up, shut-down and steam-out operations will cause different temperature differences between static equipment and piping. These operating mods need to be carefully analysed.

Tank Nozzles shall be modelled including Tank Shell Stiffness Coefficients, Radial Growth of Shell & Nozzle Rotation.

8.2.2 Rotating Equipment

Nozzles on rigid equipment such as pumps shall be modelled as a rigid anchor. Use of expansion joints shall be avoided. Expansion joints shall only be used when approved by IPMT. Additional flexibility shall be included in the layout to accommodate expansion.

8.2.3 Air Cooled Heat Exchangers

Special attention shall be paid to the correct modelling of header boxes of air-cooled heat exchangers.

Therefore, care must be taken to ensure that the mathematical model used in the piping flexibility model reflects as close as is reasonable the actual mechanical mechanism of the air fin.

8.2.4 Modelling Friction

Friction at vertical supports shall be modelled in calculations. Friction shall also be considered on guides / line stops local to strain sensitive equipment where the effects of friction could influence nozzle loadings. Where friction causes calculation convergence problems with CAESAR II analysis it may be removed but should be noted on the stress isometric. Non-friction cases are also to be considered around strain sensitive equipment. Values to be used in the calculations are given in section 7.1.

8.2.5 Modelling Supports

Vertical rest supports shall generally be modelled as +Y supports unless a hold-down is specifically specified. If convergence problems exist, then consideration shall be given to modifying specific supports to Y supports (assuming support doesn't lift) and / or removing friction at specific supports (assuming this will not have any significant influence on system / structure / equipment).

Guide / linestop supports shall be modelled with no gaps (conservative analysis assumption), unless a specifically engineered gap is required to be introduced around sensitive equipment. This must be noted on the stress isometric and ensured that pipe support will be designed with said gap.

8.2.6 Hot Sustained

To account for piping lifting-off from vertical +Y supports and the subsequent redistribution of loads, a "Hot Sustained" case run shall be performed. This is included in the Load-Case examples below.

8.2.7 Load Cases

The components used in stress analysis are defined as:

T1:	Thermal case #1 Operating temp
T2:	Thermal case #2 Maximum design temp
T3:	Thermal case #3 Minimum design temp
P1:	Design Pressure (use for all cases for conservatism)
HP:	Hydrotest pressure
D1:	Displacement due to / acting with T1, where required
D2:	Displacement due to / acting with T2, where required
D3:	Displacement due to / acting with T3, where required
U1:	Uniform (g) load case for seismic acceleration “X” direction
U2:	Uniform (g) load case for seismic acceleration “Z” direction
F1, thru F9:	Concentrated force case #1, 2, 3, 4, 5, 6, 7, 8 & 9 (e.g. relief valve or slug / slug load), where required
H	Application of spring hanger supports, where required
WIN1, 2, 3 & 4	Wind load cases #1, 2, 3 & 4
W:	Weight
WW:	Water Filled Weight
WNC:	Weight no contents
L#:	Load case # (e.g. 1, 2, 3 etc.)

8.3 Load Case Combinations

8.3.1 Design Load Cases

As a minimum, the following load cases, which include hanger sizing, nonlinear restraints and the hot sustained case, shall be used:

Line	Load Case	Type	Friction	Purpose
1	W	HGR	0	Hanger sizing - sustained
2	W+D1+T1+P1	HGR	0	Hanger sizing – operating
3	D1+T1	EXP	1	For Hot Sus (Op. temp.)
4	D2+T2	EXP	1	For Hot Sus (Max. design temp.)
5	D3+T3	EXP	1	For Hot Sus (Min. design temp.)
6	W+D1+T1+P1+H	OPE	0	Loads/deflections for operating temp.
7	W+D1+T1+P1+H	OPE	1	Loads/deflections for operating temp.
8	W+D2+T2+P1+H	OPE	1	Loads/deflections for max. des. temp.
9	W+D3+T3+P1+H	OPE	1	Loads/deflections for min. des. temp.
10	W+D1+T1+P1+H+WIN1	OPE	1	Normal operating plus wind (+X)
11	W+D1+T1+P1+H+WIN2	OPE	1	Normal operating plus wind (-X)

12	W+D1+T1+P1+H+WIN3	OPE	1	Normal operating plus wind (+Z)
13	W+D1+T1+P1+H+WIN4	OPE	1	Normal operating plus wind (-Z)
14	W+D1+T1+P1+H+U1	OPE	1	Ope. + Earthquake with friction (+X)
15	W+D1+T1+P1+H-U1	OPE	1	Ope. + Earthquake with friction (-X)
16	W+D1+T1+P1+H+U2	OPE	1	Ope. + Earthquake with friction (+Z)
17	W+D1+T1+P1+H-U2	OPE	1	Ope. + Earthquake with friction (-Z)
18	W+D1+T1+P1+H+U1	OPE	0	Ope. + Earthquake without friction (+X)
19	W+D1+T1+P1+H-U1	OPE	0	Ope. + Earthquake without friction (-X)
20	W+D1+T1+P1+H+U2	OPE	0	Ope. + Earthquake without friction (+Z)
21	W+D1+T1+P1+H-U2	OPE	0	Ope. + Earthquake without friction (-Z)
22	WNC+H	SUS	1	Pipe Empty
23	WW+HP+H	HYD	1	Hydrotest
24	W+P1+H	SUS	1	Sustained Case Condition B31.3
25	L8-L9	EXP	-	Full stress range (hot to cold) B31.3
26	L7-L24	EXP	-	Exp stress range (installed to normal)
27	L8-L24	EXP	-	Exp stress range (installed to hot)
28	L9-L24	EXP	-	Exp stress range (installed to cold)
29	L7-L3	SUS	-	Hot sustained case (normal op. temp.)
30	L8-L4	SUS	-	Hot sustained case (max. des. temp.)
31	L9-L5	SUS	-	Hot sustained case (min. des. Temp.)
32	L10-L7	OCC	-	Wind occ stress increment (+X)
33	L11-L7	OCC	-	Wind occ stress increment (-X)
34	L12-L7	OCC	-	Wind occ stress increment (+Z)
35	L13-L7	OCC	-	Wind occ stress increment (-Z)
36	L14-L7	OCC	-	Earthquake with Friction (+X)
37	L15-L7	OCC	-	Earthquake with Friction (-X)
38	L16-L7	OCC	-	Earthquake with Friction (+Z)
39	L17-L7	OCC	-	Earthquake with Friction (-Z)
40	L18-L6	OCC	-	Earthquake without Friction (+X)
41	L19-L6	OCC	-	Earthquake without Friction (-X)
42	L20-L6	OCC	-	Earthquake without Friction (+Z)
43	L21-L6	OCC	-	Earthquake without Friction (-Z)
44	L29+L32	OCC	-	Total wind occasional stress (+X)
45	L29+L33	OCC	-	Total wind occasional stress (-X)
46	L29+L34	OCC	-	Total wind occasional stress (+Z)
47	L29+L35	OCC	-	Total wind occasional stress (-Z)

48	L29+L36	OCC	-	Total EarthQ w/friction occ. stress (+X)
49	L29+L37	OCC	-	Total EarthQ w/friction occ. stress (-X)
50	L29+L38	OCC	-	Total EarthQ w/friction occ. stress (+Z)
51	L29+L39	OCC	-	Total EarthQ w/friction occ. stress (-Z)
52	L29+L40	OCC	-	Total EarthQ wo/fric occ. stress (+X)
53	L29+L41	OCC	-	Total EarthQ wo/fric occ. stress (-X)
54	L29+L42	OCC	-	Total EarthQ wo/fric occ. stress (+Z)
55	L29+L43	OCC	-	Total EarthQ wo/fric occ. stress (-Z)

The following shall be noted:

The displacement stress range shall be taken as the difference between the minimum and maximum design temperatures. The displacement stress range, from minimum installation to maximum design temperature and from maximum installation to minimum design temperature shall also be considered for all critical lines.

The effect of hot and cold bypasses shall be investigated, and the stress analysis shall investigate the full stress range that these conditions cause in the pipe.

Other external loads to be considered include impact (relief, surge, slug – see force load cases below), settlement and structural displacement.

As shown, non-linear effects shall be taken into account when setting up load cases for analysis.

Use of temporary supports for hydrotest purposes shall be avoided.

8.3.2 Load Cases with Force Application

Load Cases for nine (9) impact loads are shown below:

Line	Load Case	Type	Friction	Purpose
1	W	HGR	0	Hanger sizing – sustained
2	W+D1+T1+P1	HGR	0	Hanger sizing – operating
3	D1+T1	EXP	0	For Hot Sus (op. temp.)
4	W+D1+T1+P1 +H	OPE	0	Loads/deflections for op. temp.
5	W+D1+T1+P1+H+F1	OPE	0	Normal operating + Force (F1)
6	W+D1+T1+P1+H+F2	OPE	0	Normal operating + Force (F2)
7	W+D1+T1+P1+H+F3	OPE	0	Normal operating + Force (F3)
8	W+D1+T1+P1+H+F4	OPE	0	Normal operating + Force (F4)
9	W+D1+T1+P1+H+F5	OPE	0	Normal operating + Force (F5)
10	W+D1+T1+P1+H+F6	OPE	0	Normal operating + Force (F6)
11	W+D1+T1+P1+H+F7	OPE	0	Normal operating + Force (F7)
12	W+D1+T1+P1+H+F8	OPE	0	Normal operating + Force (F8)
13	W+D1+T1+P1+H+F9	OPE	0	Normal operating + Force (F9)
14	L4-L3	SUS	0	Hot Sus (op. temp.)

15	L5-L4	OCC	-	Loads generated by Force (F1)
16	L6-L4	OCC	-	Loads generated by Force (F2)
17	L7-L4	OCC	-	Loads generated by Force (F3)
18	L8-L4	OCC	-	Loads generated by Force (F4)
19	L9-L4	OCC	-	Loads generated by Force (F5)
20	L10-L4	OCC	-	Loads generated by Force (F6)
21	L11-L4	OCC	-	Loads generated by Force (F7)
22	L12-L4	OCC	-	Loads generated by Force (F8)
23	L13-L4	OCC	-	Loads generated by Force (F9)
24	L14+L15	OCC	-	Total Stress due to Force (F1)
25	L14+L16	OCC	-	Total Stress due to Force (F2)
26	L14+L17	OCC	-	Total Stress due to Force (F3)
27	L14+L18	OCC	-	Total Stress due to Force (F4)
28	L14+L19	OCC	-	Total Stress due to Force (F5)
29	L14+L20	OCC	-	Total Stress due to Force (F6)
30	L14+L21	OCC	-	Total Stress due to Force (F7)
31	L14+L22	OCC	-	Total Stress due to Force (F8)
32	L14+L23	OCC	-	Total Stress due to Force (F9)

9. LINE SELECTION CRITERIA FOR REVIEW

9.1 Detailed Design Phase of Project – Extent of Piping Analysis

For the Detailed Design phase of the Project, the following guidelines shall be used to create a Stress Critical Line List.

The stress critical line list identifies lines from the project line list which meet the criticality criteria outlined in section 9.1.1.

The stress critical line list shall be reviewed and updated based on the latest issued P & ID's and project line list. Stress / Flexibility analysis and / or calculations shall be carried out for the lines identified in the stress critical line list.

9.1.1 Extent of Piping Analysis

The extent of analysis is defined in one of three categories. These categories are:

1. Detailed Piping Flexibility Analysis (DA)
2. Formal Piping Flexibility Analysis (FA)
3. Formal Review (FR)

Lines that fall into these three categories are to be analysed to the levels defined below as a minimum or higher, where in the opinion of the stress engineer or checker the system warrants a higher category.

9.1.2 Detailed Piping Flexibility Analysis (DA)

Lines falling into this category are to be brought specifically to the attention of IPMT. These lines require mandatory computer analysis and the level of investigation will be established on an individual case basis. This review is to be carried out very early in the Project and prior to any formal analysis for all lines designated as “Detailed Analysis” in Section 9.2 below, plus the following cases:

1. Large diameter pipes where the pipe diameter exceeds NPS (Nominal Pipe Size) 18”.
2. Lines designed for greater than 7,000 thermal cycles (ASME B31.3, Fig. 302.3.5).
3. Lines in category “M” fluid service (per ASME B31.3).
4. Lines in section 9.1.3 (Formal Piping Flexibility Analysis) that, in the judgment of the analyst require further detailed investigation in excess of that required for Formal Piping Flexibility Analysis.
5. Lines in service below minus 46 Deg C
6. Process lines connected to Compressors.
7. Lines using vacuum stiffener rings.
8. Non-metallic piping.
9. Jacketed piping NPS 6” and larger.
10. Pipe with wall thickness >10% or < 1% of diameter.
11. Flare headers.
12. Furnace feed lines.
13. Furnace transfer lines.
14. Lines to and from high pressure exchangers.

9.1.3 Formal Piping Flexibility Analysis (FA)

All lines designated as “Formal Analysis” in Section 9.2 below, plus the following cases, require mandatory computer analysis during detailed design phase:

1. All process lines connected to Reciprocating Pumps and Compressors, Centrifugal Compressors, Blowers, Fired Heaters and Steam Generators.
2. All inlet and outlet lines to and from Turbines and Centrifugal Pumps NPS 2” and larger.
3. Lines to and from Storage Tanks, NPS 2” and larger above 150 Deg C and/or below minus 46 Deg C.
4. All lines to and from Air Coolers.
5. All lines to Storage Tanks, Pressure Vessels and Package Units NPS 8” and larger.
6. Lines containing Expansion Joints and Bellows.
7. Refractory lined pipe.
8. Lines subject to Full Vacuum.

9. PRV/PSV Discharge Lines.
10. All lines subject to significant out of balance forces whether due to surge/slugging, 2-phase flow, rapid valve operation or relief and blow down to atmosphere.
11. All Reactor lines.
12. Lines subject to large displacements/settlement.
13. Heat exchanger lines NPS 4" and larger.
14. Lines in sour service NPS 10" and larger.

9.1.4 Formal Review (FR)

All lines designated as 'Formal Review' in 9.3 Piping Criticality Diagram.

Lines in this category can be analysed by visual inspection or approximate methods using engineering judgment in accordance with ASME B31.3.

9.2 Stress Documentation

For each stress analysis report, the below listed documentation shall be supplied as a minimum. The format shall be PDF and native.

The Stress Analysis Reports shall be issued in a timely manner such that the NoBo approval is obtained prior to ordering of materials.

Stress Analysis Report documentation listing:

- Overview of reference documents used (e.g. line list, isometrics, Equipment drawings).
- Software version and configuration file.
- Overview of the stress system.
- The nodes shall be readable.
- Description of load cases and assumptions.
- Printout of the input in a readable format.
- Summary of the results clearly indicating the points of highest utilisation, highest load on supports.
- Summary of the changes to isometrics, equipment or supports from the stress analysis.
- Complete output of the calculations electronically.
- Table of loads on flanges and nozzles.
- Table of loads on pipe supports showing increment forces, moments and displacement. One table based on the plant coordinate system and a second table (for pipe shoe check) showing only the max. load based on x-axis = pipe centre line, x-axis = horizontally perpendicular to the pipe C/L (centre line) and z-axis = vertically perpendicular to the pipe C/L.
- Separate table for spring supports
- Expansion joint requirements, specification, movements, load in tie-rods, etc.

9.3 Piping criticality Diagram

This chart shown in Figure 1 shall be used to identify the required piping flexibility analysis for plant piping.

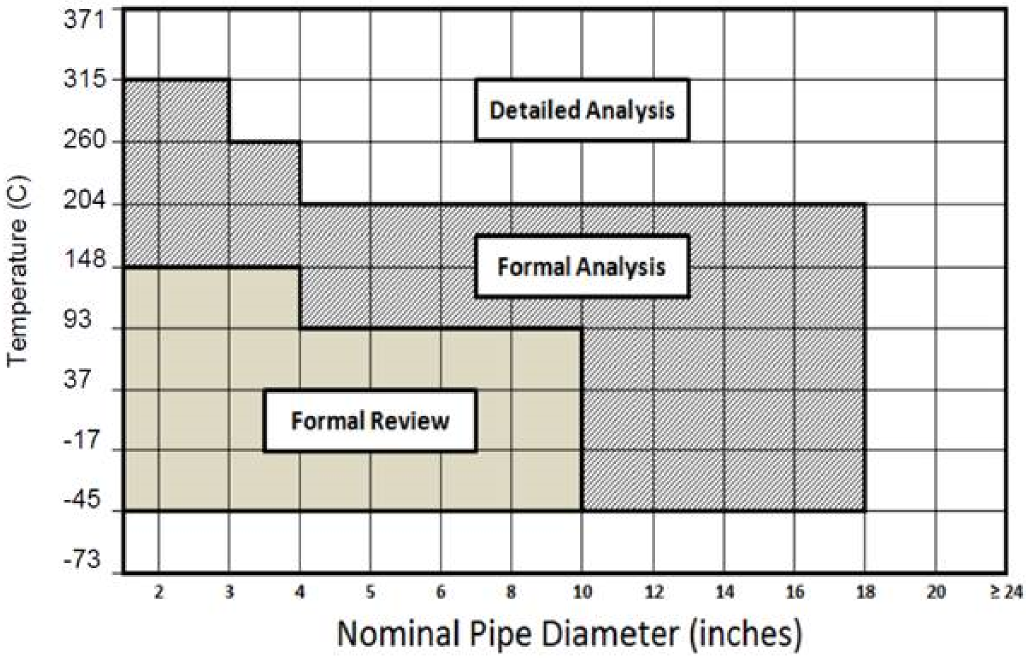


Figure 1 Piping Flexibility Analysis Requirements Chart for Power & Process Piping

10. MODULARISATION

This section covers the analysis requirements and guidelines associated with the transportation of pre-assembled racks and modules.

10.1 Basic Requirements

Stress analysis of lines shall be carried out to the requirements of the Stress Critical Line List. An additional transportation calculation shall be carried out for the sections of lines subject to transport loads.

Additional restraints shall be added to represent the temporary transportation support requirements, i.e. to restrict pipe movements during transportation. The corresponding loads for the temporary transportation supports shall be supplied to Civil for design of steelwork.

10.2 Guidelines

Piping Stress systems can typically span across several modules as shown in Figure 2.

The stress engineer shall determine where the break points are for the module limits. The Caesar model for the transportation analysis shall be trimmed to contain only the piping within the module as shown in Figures 3 and 4.

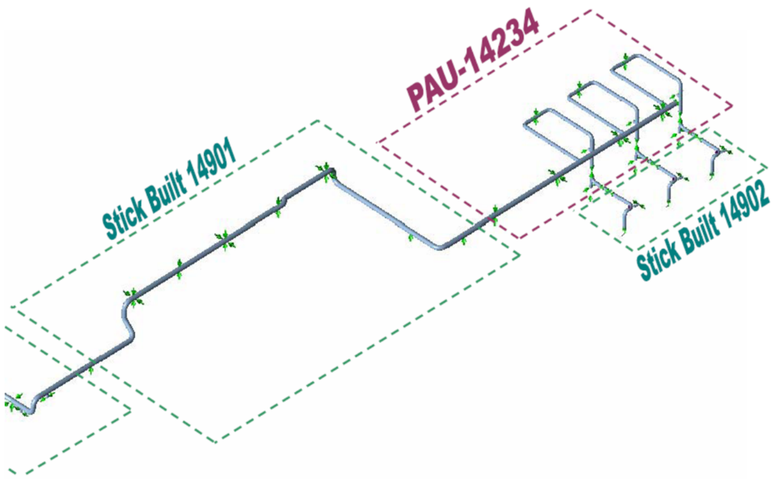


Figure 2 Typical stress system

The following guidelines should be considered for stress analysis of modules:

- Add temporary transportation supports or modify permanent supports in order to prevent the transport piping model moving laterally as a whole body and prevent excessive piping deflections (especially at pipe ends).
- If the permanent support load capacity is exceeded for transportation then add temporary transportation supports to spread the load over more support points. Example, if the piping system has a single line stop for permanent conditions and this is overloaded in the transportation case, then add one or more temporary transportation line stops to spread the load.

Determine where the break points are for the module :

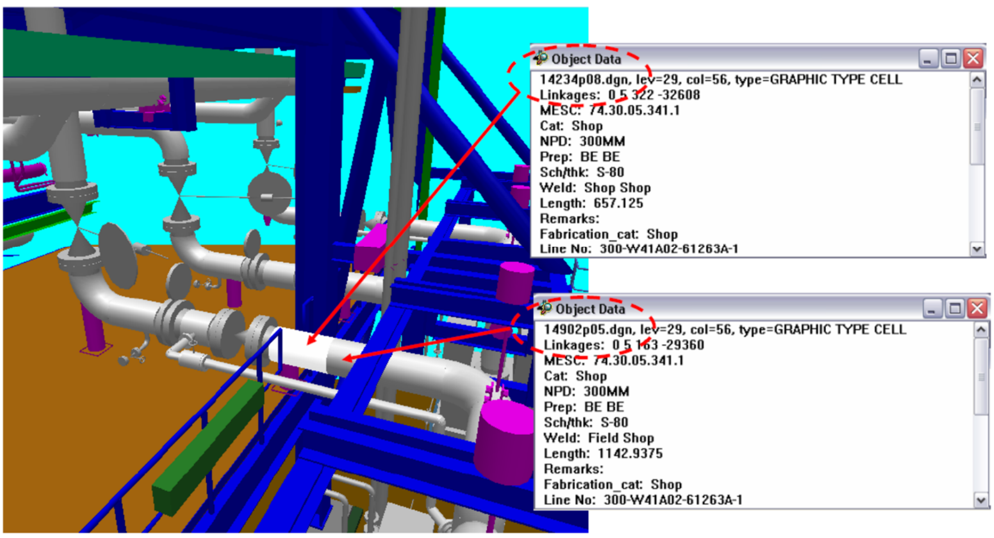


Figure 3 Module interface

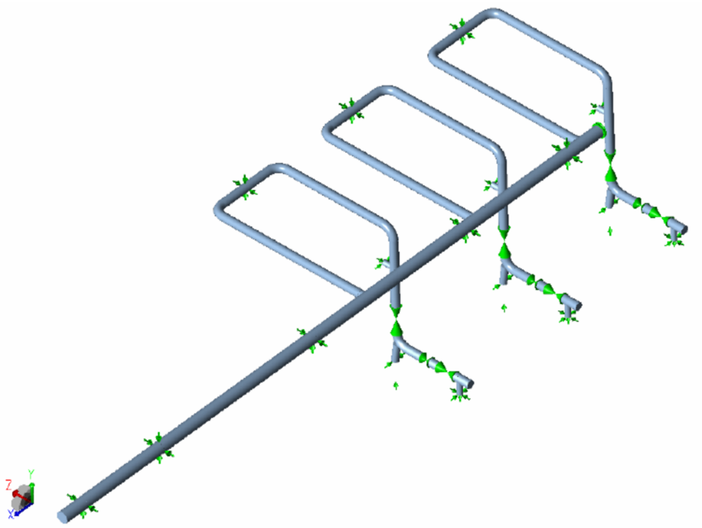


Figure 4 Trimmed model

- Gaps and Friction at the support points shall be removed.
- Spring Hangers (if any) shall be replaced by Restraint in Y-direction.
- Nozzle Disconnect. A nozzle disconnect philosophy shall be developed for the Project. This shall be done at an early stage of the Project and shall include other technical groups. Nozzles for pumps, vessels etc should have higher allowable loads when unpressurised and cold. This condition shall be included in data sheets sent out to Vendors during the project early stages. Nozzles requiring disconnect shall be noted on the Shipping GA's – where a nozzle is disconnected for transportation ensure that a note to provide a temporary closure is added to the GA.
- Caesar load cases

An example Caesar run for transportation can have the following load cases:

Case1.	U1	(Sway, Gravity load of 1g acting along X direction)
Case2.	U3	(Surge, Gravity load of 1g acting along Z direction)
Case3	WNC	(Weight No Contents)
Case4	U2	(Heave, Gravity load of 1g acting downwards along Y direction)
Case5	-yU2+xU1	(OCC- Heave + Sway)
Case6	-yU2-xU1	(OCC- Heave - Sway)
Case7	-yU2+zU3	(OCC- Heave + Surge)
Case8	-yU2-zU3	(OCC- Heave - Surge)

X, Y and Z axis orientations stand for respective transportation vehicle/ship accelerations as shown in Figure 5:

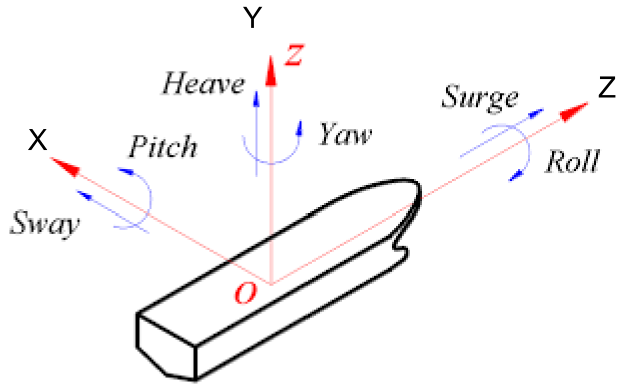


Figure 5 Orientation of axis X, Y and Z

Transport accelerations depend on the vehicle type. Accelerations on a ship shall be provided by the Naval Architect.

In cases 1, 2 and 4 the Stress Engineer shall provide 1g unit support loads to Civil Engineering for them to add their own factors.

Cases 5 to 8 shall include the actual g transportation accelerations in order to obtain actual transportation loads, stresses and displacements.

Stresses are to be compared with the allowable limits of the project design code (ASME B31.3 or applicable code). Displacements are to be kept to practical limits.

Essential Check:

Check that 1g in X and 1g in Z must produce the same total loads as the vertical load in the WNC case. Note that this balance will only work if all restraint points are included in the summation. For example, if there is an equipment nozzle in the system and the nozzle load is omitted from the load table sent to Civil Engineering then, the structural load table will not balance.

Civil Engineering will factor the 1g unit loads (cases 1, 2 and 4) in their STAAD model based on support location with respect to the overall module and location of the module on the transport vehicle/vessel. Load cases analysed by Civil Engineering include Wind effects. For cases 5 to 8, wind effects shall not be considered, however use of g-factors obtained at an extreme corner of the transportation module and with the module placed at an extreme corner of the vehicle or ship deck shall be taken into account. These shall be used for all support points within the module. If a module is particularly tall as shown in Figure 6, then it can be divided into two or three sections to allow the use of less conservative g-factors.

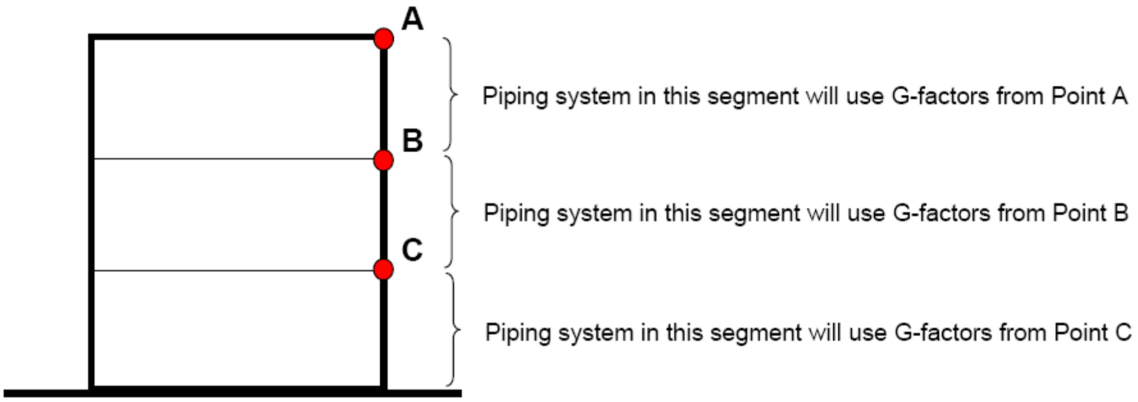


Figure 6 Example of a tall module

For non-critical lines, temporary supports, stops and guides for transportation shall be marked up on Shipping GA's. Line stops, guides and hold down supports shall be provided in order to restrict pipe movements.

10.2.1 Transportation Supports

Temporary transportation support design shall facilitate easy removal after transportation. As shown in Attachment 2, bolted supports rather than welded supports or attachments are preferred.

These supports shall be painted as per project specified colour code for identification.

Temporary resting supports, stops and guides for transportation shall be marked on Shipping GA's. However, welded attachments (trunnions) shall be marked on isometrics. A note shall be put onto the isometric to state that a particular support is for transportation purpose only.

As shown in attachment 3, cord straps shall be used as hold down supports during transportation. Loads shall be verified against the breaking strength of the cord straps. Heavy valves, 250kg and above shall have additional supports for transportation. Cord straps shall be used as hold downs, anchors and guides for small pipe diameters. For medium sized pipe diameters, cord straps shall be used as hold downs and guides only. For large pipe diameters Cord straps shall be used as hold downs only. Table 1 shows the minimum cord strap braking strength to be used.

Pipe Size	Line Stop	Guide	Hold Down	Strap Breaking Strength
DN50 & below	Yes	Yes	Yes	5kN
DN80 to DN350	No	Yes	Yes	5kN to DN150, 15kN to DN350
DN400 to DN600	No	No	Yes	15kN
Above DN600	No	No	Yes	30kN

Table 1 Minimum Cord Strap Braking Strength

11. VIBRATIONS AND DYNAMIC LOADS INDUCED FAILURES

The Guidelines for the Avoidance of Vibration Induced Fatigue Failure in Process Pipework (2nd Edition January 2008) issued by the Institute of Energy shall be used for an early screening and evaluation of piping systems that have potential issues for Project ONE.

During the design phase (SELECT, DEFINE) a Quantitative Likelihood of Failure Assessment for main lines as well as small bore connections and thermowells is to be undertaken. The Predictive Techniques and Corrective actions underlined by the standard are to be implemented.

Piping vibration sources including flow induced turbulence, mechanical excitation, pulsations due to reciprocating, screw, centrifugal compressors and pumps, pulsations due to rotating stall, pulsations due to flow induced excitation, high frequency acoustic induced excitation, surge/momentum changes due to valve operation (water hammer or gas surge), cavitation and flashing, and any other factors shortening the life span of pipe components and equipment, endangering employees and the public in general, shall be identified and addressed in the early EPC stage of the project by CONTRACTOR.

EPC CONTRACTORS (EXECUTE Phase) shall also carry out a Visual Assessment (on both piping and tubing) and implement Measurement and/or Predictive Techniques to identify any possible issues that may occur during Commissioning and Operation. Analysis shall be carried out to identify corrective actions required, these actions shall be implemented accordingly.

The API RP 688 Pulsation and Vibration Control in Positive Displacement Machinery Systems for Petroleum, Petrochemical, and Natural Gas Industry Services, First Edition shall be used when applicable when it provides more conservative operating parameters than the Institute of Energy guidelines.

The CONTRACTOR shall use a 'Specialist Consultant' to evaluate the systems vibration monitoring proposing solutions and reporting issues requiring attention in a timely manner.

ATTACHMENT 1 – DIFFERENTIAL SETTLEMENT

The following provisional differential settlement values shall apply unless or until Civil Group provide applicable differential settlement values.

Pumps to pipe racks	7mm
Pumps to drums and storage tanks	10mm
Pumps to shell and tube exchangers	10mm
Pumps to columns	7mm
Turbines to pipe racks	7mm
Shell and tube exchangers to pipe racks	10mm
Shell and tube exchangers to drums	10mm
Shell and tube exchangers to columns	10mm
Columns to pipe racks	12mm
Columns to air cooler exchangers	12mm
Tank foundation to 1st pipe support	4mm

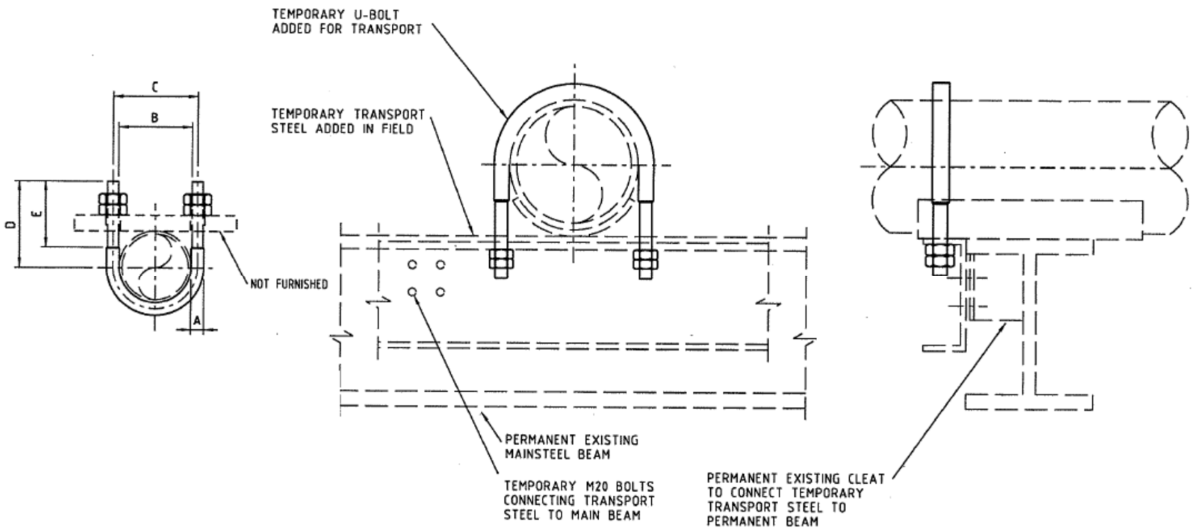
Differential settlement between piled foundations is small (less than 5mm) and is not to be taken into account in stress analysis. Care shall be taken to ensure that the first support at rotating or reciprocating equipment nozzles is adjustable and located on the same foundation as the equipment. Care should also be taken with large bore lines (>30") passing from one structure to another to ensure that the lines will be supported at both locations on either side of the structure interface.

The initial settlement at tanks during construction and testing shall be ignored since piping connections are to be made after hydrostatic testing of the tank. The maximum settlement after hydrotest is 4mm.

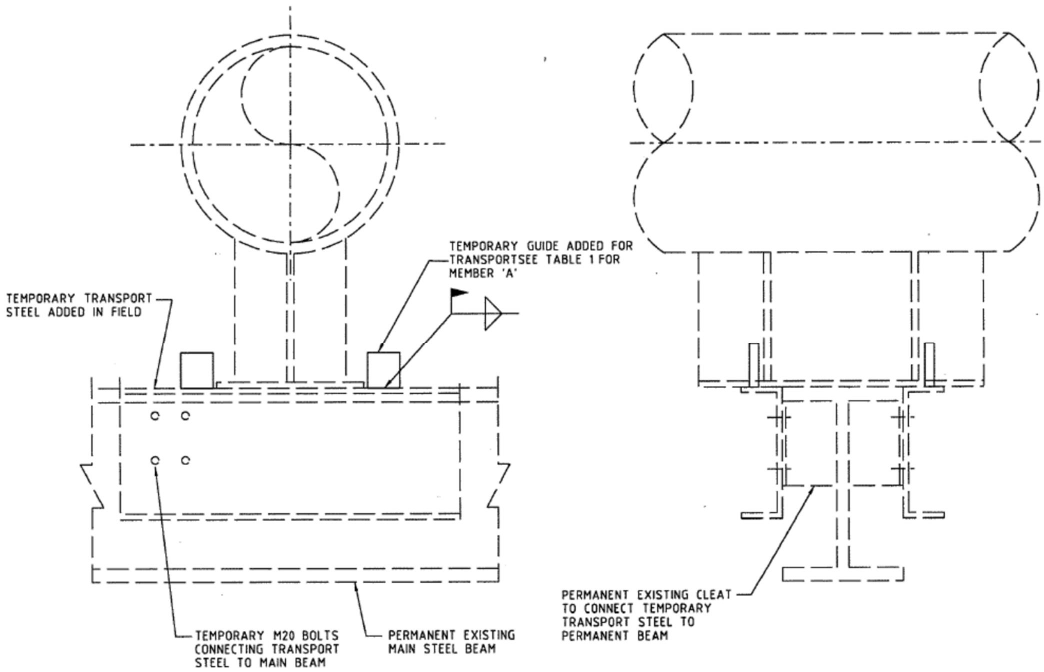
ATTACHMENT 2 – TRANSPORTATION SUPPORT SKETCHES

Transport sketches shall be provided. These shall be non dimensioned suggestions for the Yard to consider. Yard to detail and size the support.

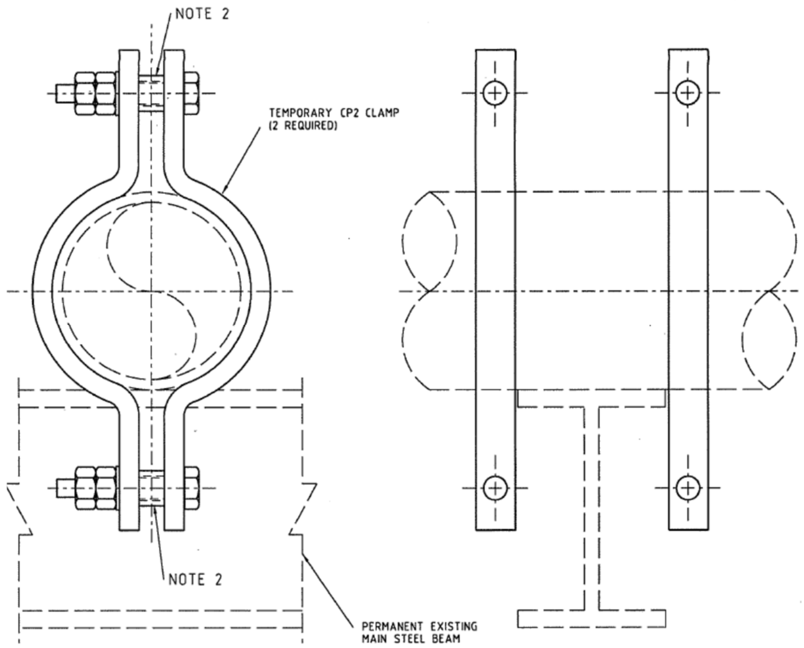
1. Transport support arrangement guide and hold down.



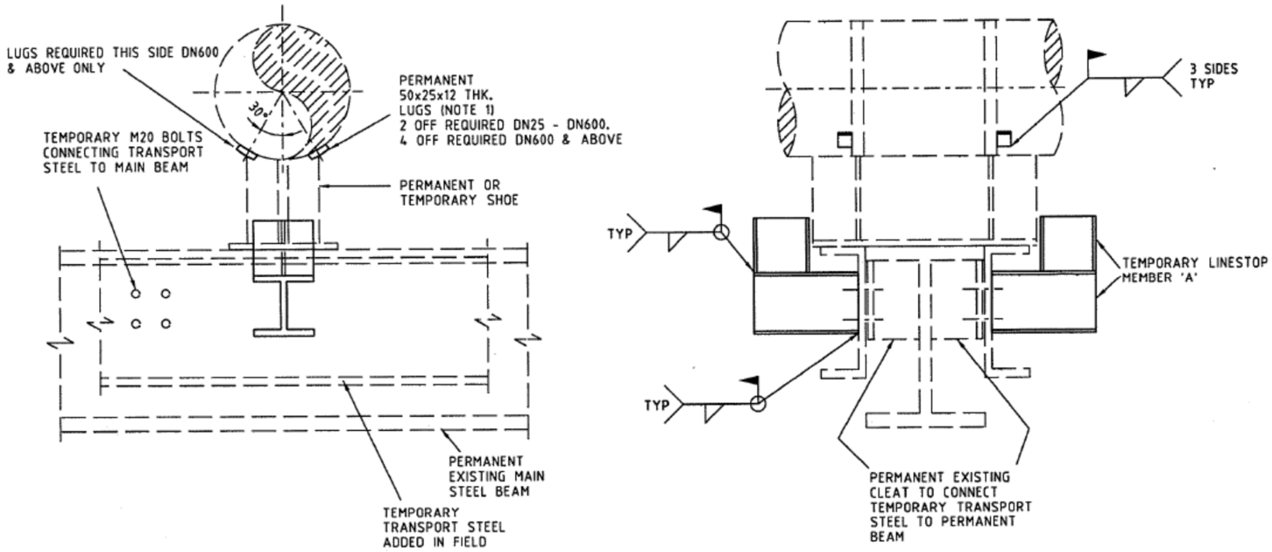
2. Transport support arrangement guide for lines on shoes



3. Transport support arrangement line stop



4. Transport support arrangement line stop for lines on shoes



ATTACHMENT 3 – TRANSPORT SUPPORT EXAMPLES

1.Cord Straps

2.Additional Steel for Control Stations